GeoEnvironmental Engineering Branch

FEASIBILITY STUDY:

STRIP DRAINS IN THE DIKES AT CRANEY ISLAND

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PREFACE

This study investigates the feasibility of installing vertical strip drains in the dikes at Craney Island. The present option under consideration is to improve the strength of the soft underlying clays by installing plastic strip drains in the dikes. The purpose of this report is to provide a feasibility analysis of placing strip drains in the dikes. The study involves reviewing data from the strip drain test section placed in the dredge material in 1993 and prior reports by WES (Fowler, 1987 and Stark,1993) and Old Dominion University (Isao Ishibashi, 1993 and 1994), as well as a stability analysis of the existing dike conditions, and an estimate of safe dike elevations after drain installation.

This effort involved four organizations. The Norfolk District was responsible for coordinating the design effort, managing the field investigations, and preparing the design documents. In addition, the Norfolk District was responsible for reviewing and summarizing available information in sufficient detail to perform schematic design. Old Dominion University, Norfolk, Virginia helped the Norfolk District with interpretation of the data, and providing research. The U. S. Army, Waterways Experiment Station (WES), Vicksburg, Mississippi provided research in support of the project. The University of Illinois, Urbana assisted the WES with the research.

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INTRODUCTION

Background

The Craney Island Dredge Material Management Area (CIDMMA) is a 2,500-acre confined dredged material containment site located near Norfolk, Virginia. It is managed by the U.S. Army Corps of Engineer District, Norfolk . The Norfolk District completed construction of Craney Island in January 1957. The original construction provided for a dike elevation of +8 MLW with an estimated storage volume of 100 million cubic yards. Norfolk District has increased the capacity of Craney Island through three major dike raising efforts. The present plan is to raise the West dike to elevation +34 with a 1000 foot wide underwater stability berm along the outer toe of the dike. This plan also includes raising the north and east perimeter dikes to elevation +40 MLW with inward setbacks from the dike perimeter road of 420 feet and 450 feet, respectively.

Purpose and Scope

The U.S. Army, Corps of Engineers, Norfolk District is initiating design in support of a construction effort to increase the storage capacity of Craney Island. The present option under consideration is to improve the strength of the soft foundation clays under the dikes by installing plastic strip drains through the dikes. The purpose of this report is to provide a feasibility analysis of placing strip drains in the dikes. The preparation of the report involved reviewing data from a strip drain test section placed in the dredge material in 1993; reviewing prior reports by WES (Fowler, 1987 and Stark,1993) and Old Dominion University (Isao Ishibashi ,1993 and 1994); and analyzing the slope stability of the dikes with and without the drain installation.

The scope of this report is limited to using available site information and research studies. The following tasks are part of the study:

a. Review data from previous research reports.
b. Compile and review field data from the strip drain test section.
c. Compare research data to back-calculated data obtained from the test section.
d. Determine the present and after drain installation stability of the dikes.
e. Determine the feasibility of placing strip drains in the dike and make recommendations for concept design.
f. Provide an instrumentation monitoring plan for the project.

PREVIOUS RESEARCH DATA

In 1987 WES analyzed the stability of the perimeter dikes in their report, Perimeter Dike Stability Analyses Craney Island Disposal Area, Norfolk District, Norfolk, Virginia. The report is a collection and statistical evaluation of soil data collected from 1948 to 1983. Testing included in situ field vane shear strength and conventional laboratory shear strength data as well as boring log information. They also evaluated innovative procedures for improving the foundation strength. This report concluded that, with setbacks, raising the north and east dikes to el. +40 feet is feasible. Additionally, it is possible to raise the west dike to el. +34 feet by constructing an underwater stability berm on the toe. They also concluded in 1987 that, given the alternatives available at that time, the use of "wick drains" in the dikes would not be economically feasible. They concluded that too much of the "wick drain" would be left in the dike section causing the project to not be cost effective.

In 1991 Dr. Timothy Stark presented the report Feasibility of Installing Vertical Strip Drains to Increase Storage of Craney Island Disposal Area. The report provided a preliminary spacing and cost for installing vertical strip drains in the containment areas of Craney Island. Stark addressed the fact that the piezometers in the dikes indicated that excess pore-water pressures exceeded the ground surface by 25 feet in some locations. The dissipation of these excess pore-water pressures would result in substantial consolidation settlement and thus increased storage capacity. Stark predicted a range of settlements in the dredge material of approximately 5 feet to 20 feet. He estimated that the cost for installing drains in the entire containment area would be $ 25.8 M. The drain installation would also provide added stability for the dikes as the foundation clays consolidated and increased in shear strength.

Dr. Timothy Stark, under contract and in conjunction with, WES prepared the report on Long-Term Performance of Vertical Strip Drains in Consolidating Confined Dredged Material in 1993. The report investigated the long-term performance of vertical strip drains. Dr. Stark concluded that the long term functioning of the drains at Craney Island would still be questionable since the longest duration of functioning drains in the field at that time was three years.

Also in 1993, Old Dominion University compiled the data for all previous soil testing at Craney Island in their report, Geotechnical Engineering Support for Craney Island Project - Phase I: Preliminary Investigation. In this report, ODU reviews, evaluates and interprets existing field and laboratory data available on the subsoil conditions in the disposal area. They also used the one-dimensional consolidation computer program, CSETT (Templeton, 1983) to calculate the induced stresses and consolidation progress under the dikes since the 1950s. ODU used the profiles proposed by Fowler in 1987 to calculate the settlement under the dikes.

In 1994, ODU presented the Phase II report: Laboratory Determination of Soil Properties and Levee Stability Analysis. Phase II provides additional shear strength parameters for the foundation clay. It also analyzes the stability of the dikes using a finite difference numerical code called "FLAC". According to this report the west and north dikes have adequate factors of safety, 1.98 and 1.88 respectively, but the east dike has a factor of safety of only 1.09. This report was the first indication that the east dike may be the least stable of the three.

The GeoEnvironmental Branch reviewed the soil parameters and dike profiles used by ODU to evaluate the validity of their findings. During this review we noted that ODU had improperly used the west dike soil parameters for both the west and east dike analyses. The soils under the east dike have traditionally been coarser and exhibited higher shear strengths than those under the west dike. We determined that the east dike's stability was not in question when the soil strengths were increased to reflect the actual field conditions.

A preliminary report prepared by Tim Stark, University of Illinois, in 1994, Undrained Strength Stability Analysis for West Perimeter Dike at the Craney Island Dredged Material Management Area, Norfolk, Virginia provides a factor of safety for the west dike of 1.9. This value agrees with the value obtained by the ODU report. Dr. Stark did not address the north or east dikes in his report. He did address the use of strip drains in the west dike. He stated that the use of vertical strip drains should allow the west perimeter dike and dredge material to be raised to el. +58 ft and +54 ft CEMLW, respectively.

The 1996 report Strip Drain Test Section in Craney Island Dredged Material Management Area by Timothy Stark discusses in detail the 240,000 ft^2 test section placed in the north compartment in 1993 (see Figure 1). The test section was constructed to evaluate the effectiveness of prefabricated strip

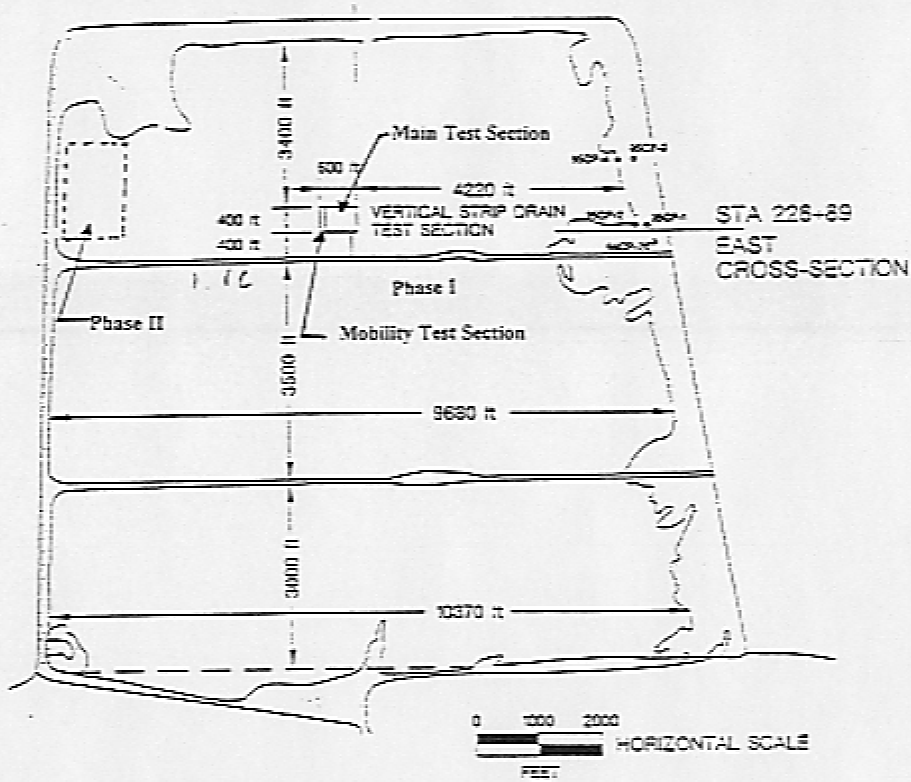

Figure 1. Plan View of Craney Island and Location of Vertical Strip Drain Test Section

drains in consolidating the dredged fill and underlying marine clay, and thus increasing the storage capacity of the facility. Settlement plates installed in the main test section have settled approximately 8 feet and the mobility test section has settled approximately 6 feet in 28 months. Stark uses the measured settlements to estimate field values for the compression index, C_c and the horizontal coefficient of consolidation, C_h. He suggests that these values (C_c = 0.71 and C_h = 1.3E-03 m^2/day) should be used to design future strip drain installations at Craney Island.

FIELD DATA ANALYSIS

Strip Drain Test Section Results

In February 1993 the Norfolk District and WES finished constructing a 240,000 square foot vertical strip drain test section in the north compartment of Craney Island (see Fig. 1). The test section consisted of a main test pad covered with a 2 foot thick sand blanket to promote surface drainage and support the installation equipment. The main test pad measured 500 ft by 400 ft. The mobility test pad was 100 feet by 400 feet and did not have the sand blanket. The objective of the mobility test pad was to determine if the sand blanket was needed to facilitate drain installation. Dr. Tim Stark, University of Illinois, prepared a progress report "Strip Drain Test Section in Craney Island Dredged Material Management Area" reviewing the data available through August 1993. Dr. Stark used the preliminary data from the test section to estimate the magnitude of consolidation settlement.

In his original report, Stark predicted a settlement range of 6.2 to 7.8 feet (1.9 m to 2.4 m) in the test section. He also predicted 90% consolidation in 400 days. He used a range of values for the compression index (C_c) from 0.549 to 1.362 to determine the total possible settlement. To determine the time of settlement due to radial drainage he used a value of 0.1225 ft^2/day (0.0116 m^2/day) for the horizontal coefficient of consolidation (C_h), (Stark, 1993).

Validation of Cc – Compression Index

In 1996 Stark prepared the final report on the strip drain test section. Stark graphically presented the settlement plate measurements for both the mobility and main test sections. Figure 2 shows the semi-logarithmic plot of these measurements. Both of these plots indicate that the test pad had not reached 100% consolidation as of the last reading in July 1995. Additional readings could not be taken since the north compartment has been actively used for dredge material placement since that time. Stark used this information to back calculate a C_c 'field value' of 0.71 for Craney Island (Stark, 1996).

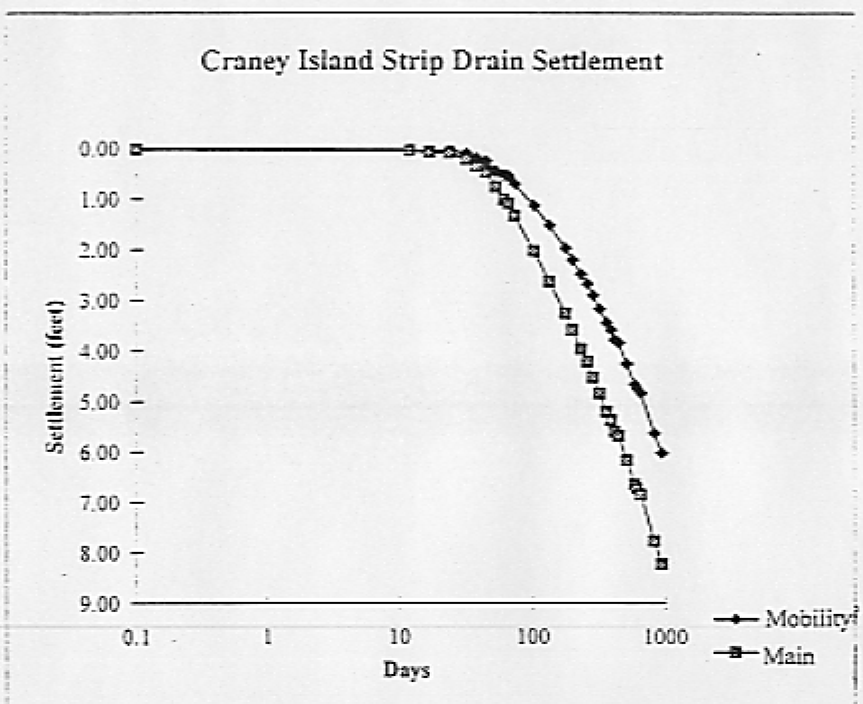

Fig. 2 Semi Logarithmic Presentation of Settlement Plate Measurements in Mobility Test Section and Main Test Section

Validation of Ch - Coefficient of Horizontal Consolidation

Stark also back calculated C_h from the settlement data shown in Figure 2. Figure 3 presents the measured and Stark's estimated consolidation settlement versus time for the main test section. The estimated relationships were obtained using the original design parameters from the feasibility reports. The range in time rate of settlement was estimated using the degree of consolidation calculated using the final consolidation settlements (4.8 and 9.75 feet) that correspond to Cc equal to 0.41 and 0.79, respectively. The measured settlements correspond to settlement plate SP-5, which is located at the center of the main test section. It can be seen in Figure 3 that the estimated time rates of settlement are not in agreement with the measured values. The measured values were then used to back calculate C_h. Based on this analysis, Stark determined that the field value for C_h of 0.0013 m2/day should be used in determining time rate of consolidation for the marine clay at Craney Island.

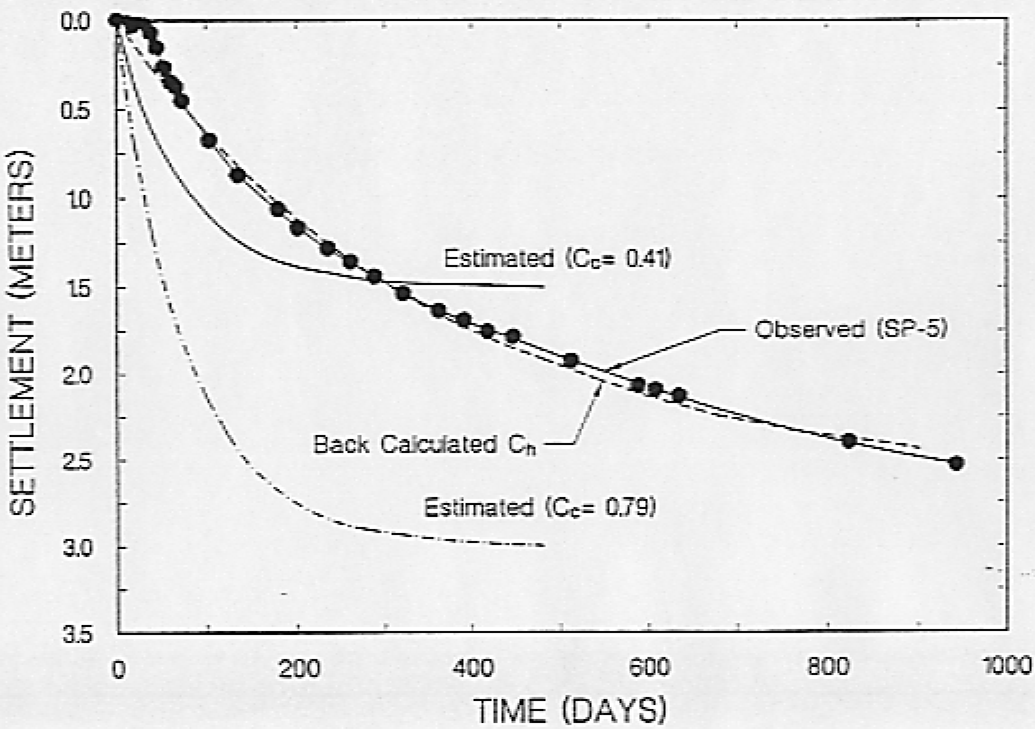

Figure 3 Measured and Estimated Time Rate of Consolidation Settlement for Main Test Section

SLOPE STABILITY ANALYSIS

GeoEnvironmental Branch performed slope stability analyses on both the north and east dikes. We determined the existing factors of safety, the maximum dike elevation without remedial soil improvements, the maximum dike elevation with the use of strip drains, and maximum dike elevation with the use of lightweight fill materials. Tables 1 and 2 show the summary of our findings.

East Dike	Dike Elevation	Dredge Material Elevation	F.S.
Existing Stability Analysis			1.76
Maximum Elevation without Strip Drains	45	41	1.28
Maximum Elevation with Strip Drains (350 feet wide)	65	61	1.37
Maximum Elevation with Strip Drains (430 feet wide)	75	71	1.34

Table 1. Summary of Slope Stability Analysis for the East Dike

North Dike	Dike Elevation	Dredge Material Elevation	F.S.
Existing Stability Analysis			1.85
Maximum Elevation without Strip Drains	50	46	1.28
Maximum Elevation with Strip Drains (400 feet wide)	65	61	1.37
Maximum Elevation with Strip Drains (400 feet wide) plus berm	70	66	1.31
Max Elevation Lightweight fill and berm	60	56	1.34

Table 2 Summary of Slope Stability Analyses for the North Dike

West Dike Slope Stability Analysis

An additional slope stability analysis for the west dike was not performed. We used the values presented by Stark in his 1994 report Undrained Strength Stability Analysis for West Perimeter Dike at the Craney Island Dredged Material Management Area, Norfolk, Virginia. We concur with Stark's conclusion that the existing West Dike has a factor of safety of 1.9. He also states that with the use of vertical strip drains Norfolk should be able to raise the west dike dikes to elevation +58, with a dredge elevation of +54, and maintain a factor of safety of 1.3. (see Table 3)

Table 3. Results of Stark's Stability Analyses for the West Dike

Stability Run	Dike Crest Elevation (ft)	Dredged Material Elevation (ft)	Analysis Comments	Critical Circle Center X (ft)	Critical Circle Center Y (ft)	Critical Circle Radius (ft)	Circle Tangent Elevation (ft)	Side Force Inclination (degrees)	Strength Parameters from West Perimeter Dike — Factor of Safety: January, 1994 Geometry	Strip Drains and Su/p' = 0.22	Strip Drains and Su/p' = 0.25
a	23.2	19	1994 Geometry & Shear Strengths	60.50	120.25	207.50	-87.25	1.17	1.91	—	—
b	33	29	Raise Dike to FS = 1.3	102.75	163.50	253.50	-88.00	1.73	1.30	—	—
c	34	30	1993 Strengths and Analysis 32 Geometry	62.75	260.00	339.20	-79.20	1.90	1.38	—	—
d	37.5	33.5	1993 Strengths and Raised Analysis 32 Geometry	94.50	322.50	401.95	-79.45	1.95	1.30	—	—
e	23.2	19	1994 Geometry & Strip Drain Strengths (.22)	70.00	138.75	198.50	-59.75	2.29	—	2.43	—
f	23.2	19	1994 Geometry & Strip Drain Strengths (.25)	71.00	141.75	198.50	-56.75	2.64	—	—	2.48
g	33	29	Maximum Geometry & Strip Drain Strengths (.22)	107.75	195.25	257.75	-62.50	3.24	—	1.92	—
h	33	29	Maximum Geometry & Strip Drain Strengths (.25)	105.25	207.25	266.00	-58.75	3.51	—	—	2.15
i	58	54	100% Consolidation & Raise Dike to FS = 1.3	191.75	443.45	514.75	-71.30	4.16	—	1.30	—
j	66	62	100% Consolidation & Raise Dike to FS = 1.3	222.50	579.95	651.25	-71.30	4.42	—	—	1.30

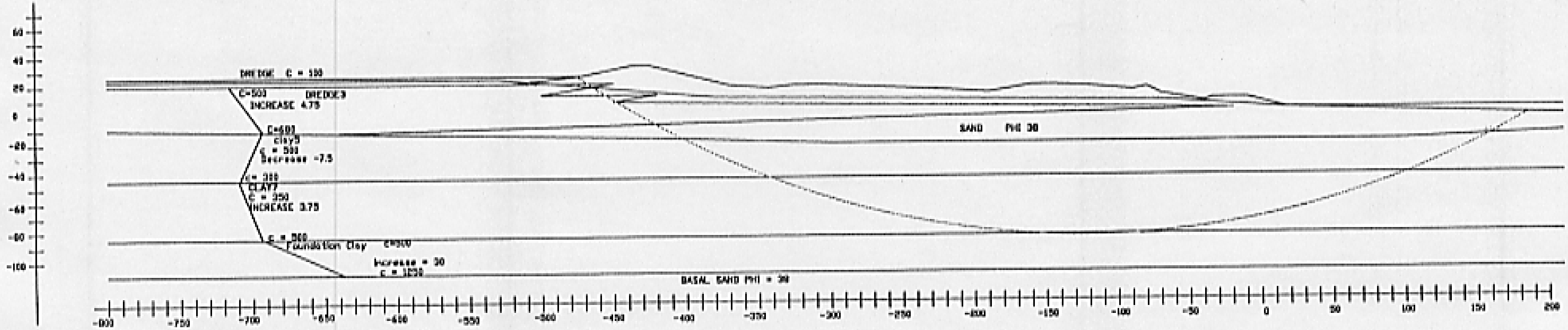

Figure 4.

EAST LEVEE STABILITY ANALYSIS
EXISTING CONDITIONS AT STA 228 - USING 1995 CPT DATA
FS = 1.76

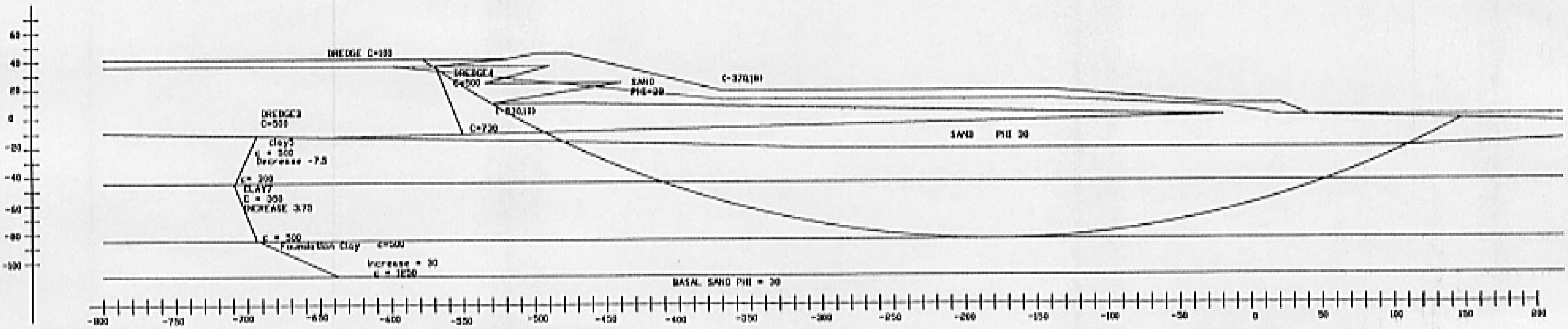

Figure 5.

EAST LEVEE SLOPE STABILITY ANALYSIS
MAXIMUM LEVEE HEIGHT WITHOUT STRIP DRAINS
LEVEE AT ELEV. +45 DREDGE AT ELEV. +41
FS = 1.28

East and North Dike Analysis

The GeoEnvironmental Branch used UTEXAS3 to analysis the stability of the east and north dikes and the effect of placing strip drains in the dike material to increase storage capacity. We used the slope geometry provided by the 1993 survey and the data obtained from CPT tests performed in the area.

East Dike Stability Analysis

We used the 1995 CPT values and the survey in the area of Station 228 for the east dike analysis. Using these values we determined that the existing dike has a factor of safety of 1.76 (Figure 4). In our analysis, we continually raised the height of the dike on a 4H:1V slope to determine the maximum dike elevation. We determined that we would be able to raise the height of the east dike to elevation +45 with dredge material to elevation + 41 and still maintain a factor of safety of 1.28, without installing vertical strip drains (Figure 5).

The CPT's in the area indicated that the marine clays under the dikes are underconsolidated. Values of Su were estimated using an undrained strength ratio (Su/P') of 0.22 and 0.25 and the effective vertical stress under the levee after 100 % consolidation. The relationships between undrained shear strength (Su) and depth after 100% consolidation are presented in Figure 6. We used the average of these two values to conduct our stability analyses. Comparing the calculated profiles of Su in Figure 6, before and after strip drain installation, provides an insight to the degree of underconsolidation that currently exists in the dredged material and marine clay.

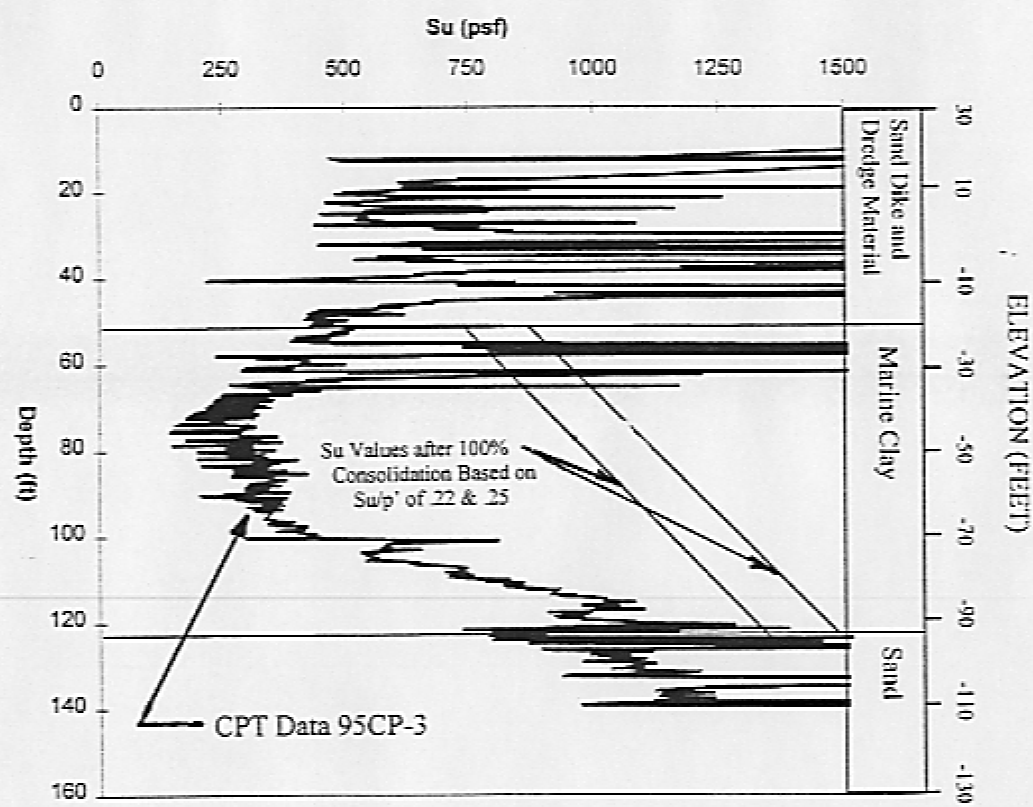

Figure 6. Undrained Shear Strength Profile Below Craney Island East Levee

We then analyzed the effect of placing strip drains from the top edge of the existing dikes as far eastward as possible. Since the Navy has a pipeline along the baseline of the east side of the island, we assumed no strip drains were installed closer than 100 feet west of the pipeline to ensure that the settlement would not interfere with the stability of the pipe. This provided a 350 foot wide area of drains from 130 feet west of the baseline to 480 feet west of the baseline. After 100% consolidation the strip drain analysis showed that the dikes could be raised to elevation +65 with a dredge material elevation of +61 feet and maintain a factor of safety of 1.37 (Figure 7).

We then extended the strip drain area width by 80 feet to the west. This simulated placing drains in an 80 foot wide area after the levee elevation had reached +50 feet. By doing this we could raise the height of the dikes to elevation +75, with a dredge material elevation of +71 and maintain a factor of safety of 1.3 (Figure 8). Installing additional drains into the dredge material area or further east did not increase the factor of safety for the slope. Therefore, based on our analysis, the optimum width of drain installation along the east dike is 430 feet.

North Dike Stability Analysis

We used the values obtained from 94CP-14 and the dike geometry from the 1993 survey at Station 162 to determine the stability of the north dike. From these values we determined that the existing dike has a factor of safety of 1.85 (Figure 9). This value agrees well with the value of 1.88 obtained by Ishibashi in his 1994 report.

We then raised the dike and dredge material heights to determine the maximum dike elevation without the use of stripdrains, again using a slope of 4H:1V. From this analysis we determined that the north dike could be raised to elevation +50, with the dredge material at elevation +46. This provides a factor of safety of 1.28 if the slope is maintained at 4H:1V (Figure 10). If the slope is flattened to 8H:1V we can achieve a factor of safety of 1.34 (Figure 11). The small increase in safety factor may not warrant the loss of dredge material storage that would be a consequence of the flatter slope.

The CPT's in the area of the north dike indicate that the marine clays under the dike are underconsolidated. Values of Su were estimated using an undrained shear strength ratio (Su/P') of 0.22 and 0.25 and the effective vertical stress under the levee after 100 % consolidation. The relationships between undrained shear strength and depth after 100% consolidation are presented in Figure 13. We used the average of these two values to conduct our stability analyses.

We then analyzed the effect of placing the strips drains along the north dike. The drains were placed in an area from the north edge of the perimeter road to the top of the existing dikes. The average width of this area is 400 feet. The maximum elevation we can construct the north dike to and maintain a slope of 4H:1V is elevation 65 feet (Figure 12).

We also looked at adding extra stability to the toe by constructing a berm or possibly adding rip rap materials between the perimeter road and the water's edge. Building this berm would allow us to construct the dikes up to elevation +70 with a factor of safety of 1.3 (Figure 14).

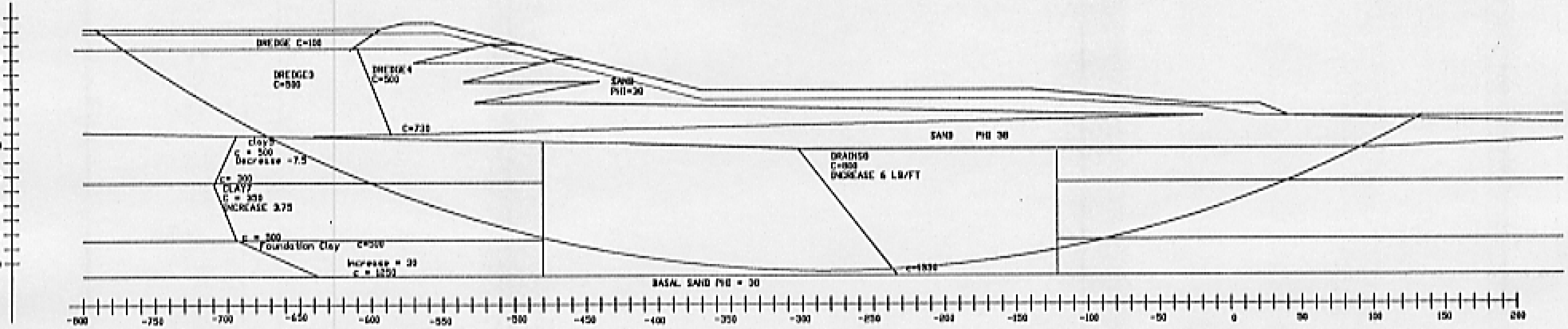

Figure 7.

EAST LEVEE SLOPE STABILITY ANALYSIS
MAXIMUM LEVEE HEIGHT WITH DRAINS INSTALLED FROM -480 TO -130
MAX LEVEE HEIGHT: ELEV. +65 DREDGE HEIGHT: ELEV. +61
FS = 1.369

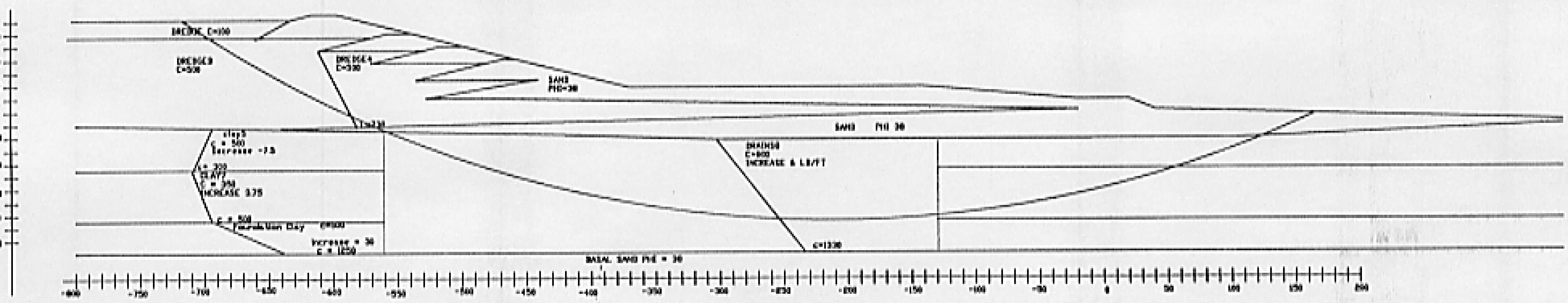

Figure 8.

EAST LEVEE SLOPE STABILITY ANALYSIS
MAXIMUM LEVEE HEIGHT WITH DRAINS INSTALLED FROM -560 TO -130
MAX LEVEE HEIGHT: ELEV. +75 DREDGE HEIGHT: ELEV. +71
F.S. = 1.34

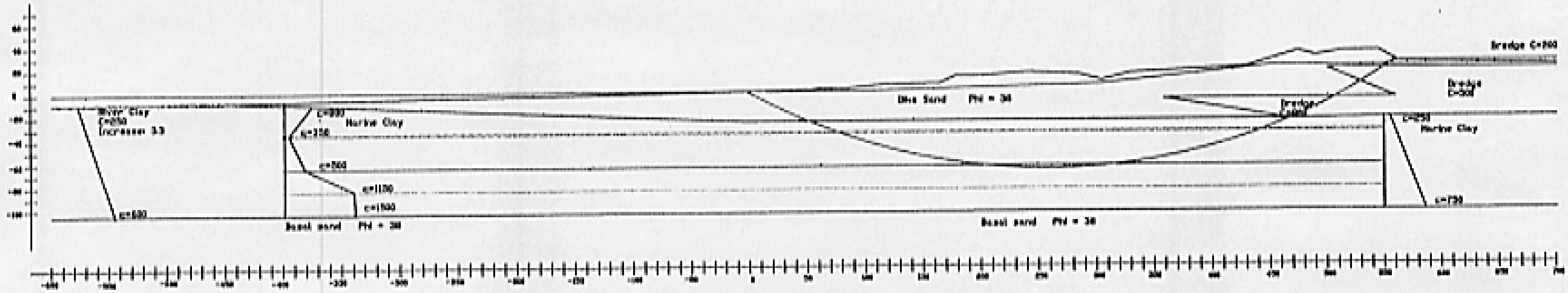

Figure 9. NORTH LEVEE SLOPE STABILITY ANALYSIS
EXISTING CONDITIONS (1993 SURVEY)
F.S. = 1.85

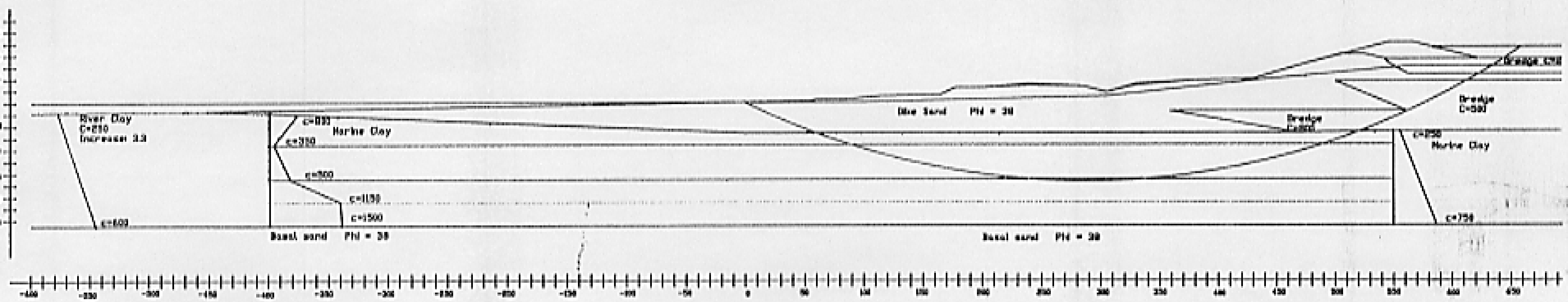

Figure 10.
NORTH LEVEE SLOPE STABILITY ANALYSIS
LEVEE TO ELEV. +50
F.S. = 1.28

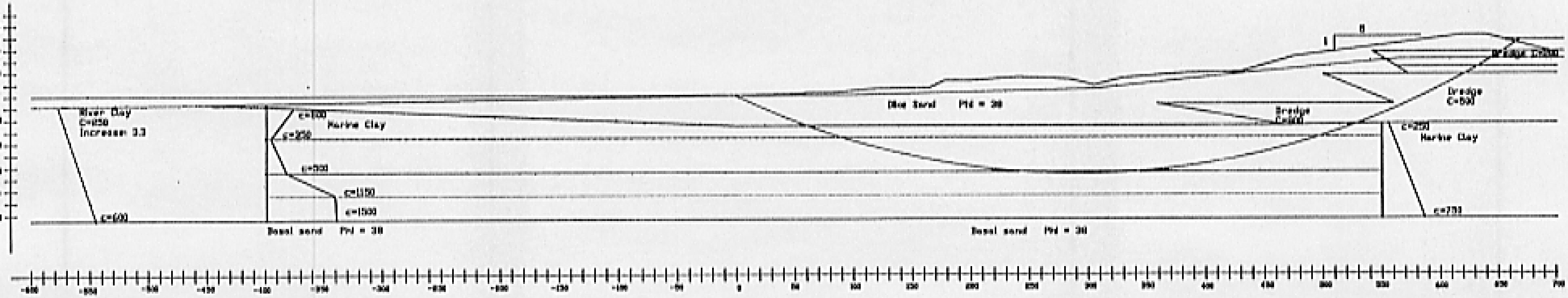

Figure 11.
NORTH LEVEE SLOPE STABILITY ANALYSIS
LEVEE TO ELEV. +50 SLOPE 8H:1V
F.S. = 1.34

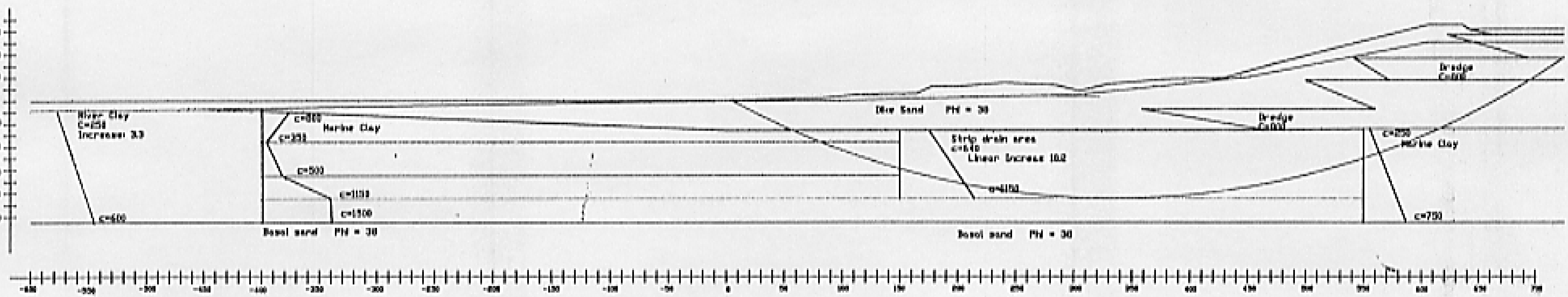

Figure 12.
NORTH LEVEE SLOPE STABILITY ANALYSIS
LEVEE TO ELEV. +65 DRAINS FROM 150 TO 550
F.S. = 1.37

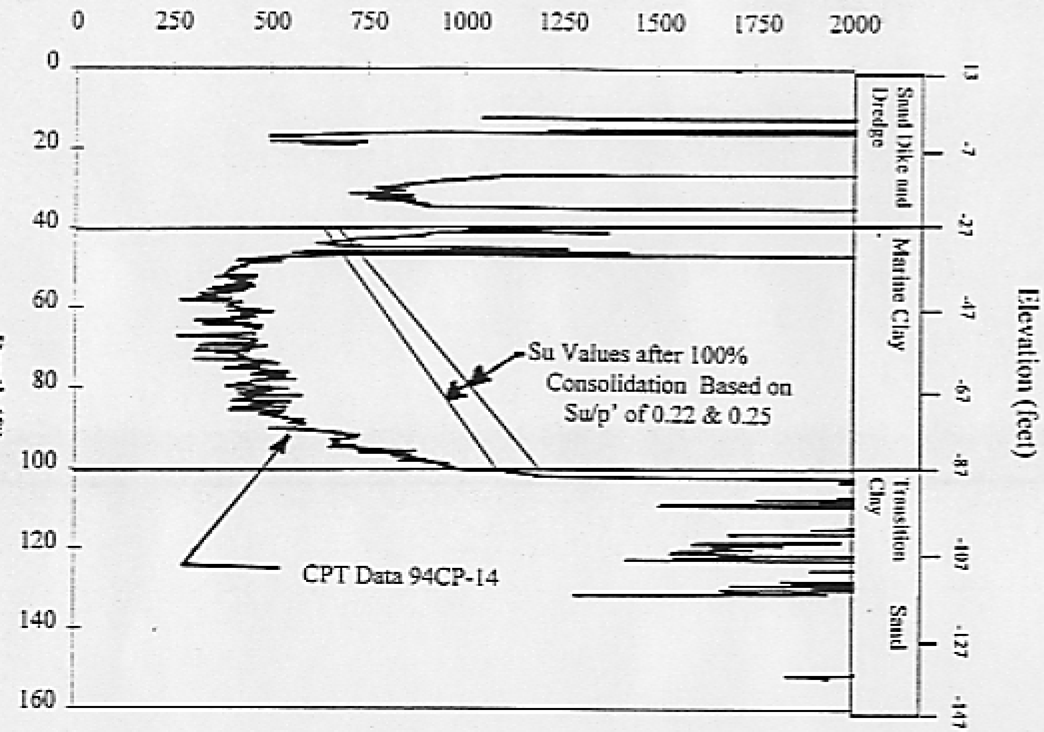

Figure 13. Undrained Shear Strength Profile Below Craney Island North Dike

Alternative Designs for the North Dike

The north dike has had a great deal of rip rap and concrete construction debris placed between the perimeter road and the dike road. This rip rap may prevent us from being able to install strip drains as we have shown here. Therefore, we investigated using a lightweight dike material in place of the strip drains. We replaced the sand dike material with lightweight aggregate materials with soil properties of phi = 45 degrees and a saturated weight of 65 pcf. This material was placed starting at elevation +40 feet. We also added the stability berm. This configuration would allow us to raise the dike to elevation 6 feet with a factor of safety of 1.34 or to elevation 65 with a factor of safety of 1.19 (Figure 15).

STRIP DRAIN DESIGN AND PROJECT COSTS

Placement of Drains

For the stability analysis we calculated the increase in shear strength that corresponds to placing drains in as wide of an area under each of the dikes as was physically possible. Over the years, rip rap and concrete have been placed along the shores of Craney Island. This concrete limits the outer edges of the drain area.

The present elevation of the dikes limit the inner edges of the strip drain areas. To install drains through the dredge material near the dike edge we need equipment that is lightweight since the dredge material will not support a large crane. Additionally, the equipment must be able to provide enough force to install the drains through the original sand dike some 30 feet below the dredge surface. During installation of strip drains in the west levee we attempted to provide a sand and geotextile blanket for

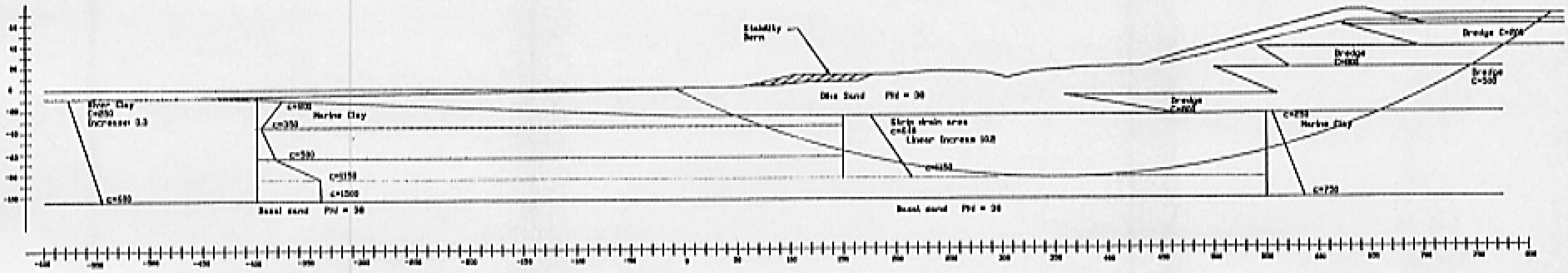

Figure 14.

NORTH LEVEE SLOPE STABILITY ANALYSIS
LEVEE TO ELEV. +70   DRAINS FROM 150 TO 550 and Berm
F.S. = 1.31

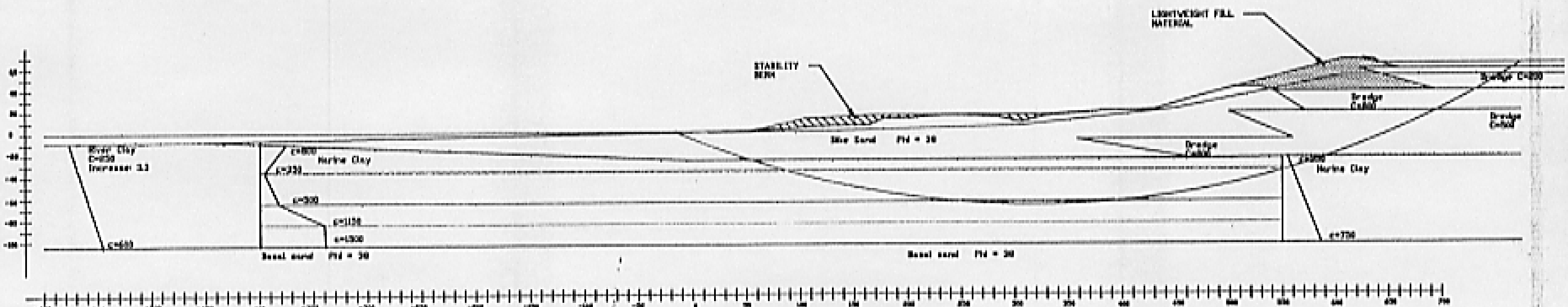

Figure 15.

NORTH LEVEE SLOPE STABILITY ANALYSIS
LEVEE TO ELEV. +65   LIGHTWEIGHT FILL ON LEVEE
AND STABILITY BERM F.S. = 1.25

equipment to install strip drains in the dredge material around the weir along the west dike. The blanket was not secure enough for the large crane and the lightweight equipment could not push through the original sand dike. Therefore, we decided, for this report, to limit the placement of drains to the inside edge of the dikes. For the east dike, the outside edge was also limited by the location of the Navy pipeline. Figure 16 presents a map of the design placement of strip drains used in the stability analyses.

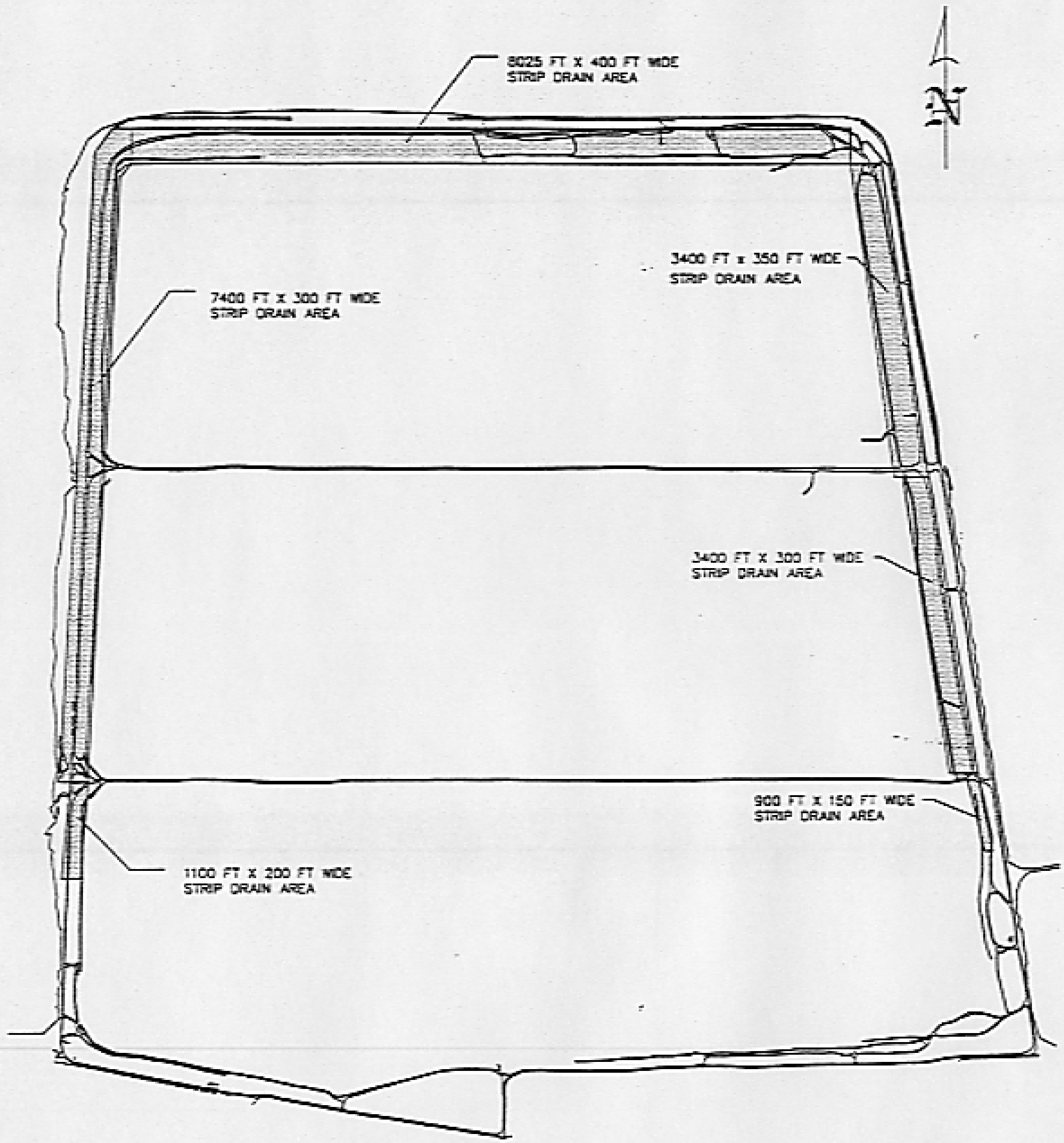

Fig. 16. Proposed Areas of Vertical Strip Drain Installation, Craney Island

To determine the cost of placing the drains in this area we used the costs from the last two projects which had a drain spacing of 12 feet. The unit cost for installing the drains was $.95 / linear foot of installed drain. We used an average installation length of 130 feet. Table 4 provides the estimated costs for installing the drains in all three dikes.

Settlement Under the Dikes

Dike subsidence has continued to occur along the perimeter dike alignment since Craney Island was completed in 1957. During design and prior to construction it was estimated that dike settlement would exceed 7 feet. Dike subsidence includes a combination of settlement caused by consolidation and displacement of the dike foundation caused by bearing capacity failure and long-term plastic flow of the soft foundation material. According to the soils profiles of the existing dikes the marine clay is now at an average elevation of -25 feet, some 15 feet below the original river bottom. How much of this 15 feet is settlement and how much is displacement is unknown. The graphs from the CPT data in Figures 6 and 13 indicate that only the top and bottom 10 feet of the marine clay may be 100% consolidated, indicating that the settlement portion of the dike subsidence, to date, is likely very small.

Strip Drain Installation Costs:

West Dike	Length	Width	Area (sf)	No. of Drains	Linear Ft	Cost $
South Cell	1,100	200	220,000	3,033	394,290	$374,576
Center Cell	3,700	300	1,110,000	15,350	1,995,500	$1,895,725
North Cell	3,700	300	1,110,000	15,350	1,995,500	$1,895,725
				Engineering		$208,301
				Contingencies		$416,603
				Total:		$4,790,929

East Dike	Length	Width	Area (sf)	No. of Drains	Linear Ft	Cost $
South Cell	900	150	135,000	1,850	240,500	$228,475
Center Cell	3,400	300	1,020,000	14,100	1,833,000	$1,741,350
North Cell	3,400	350	1,190,000	16,450	2,138,500	$2,031,575
				Engineering		$200,070
				Contingencies		$397,300
				Total		$4,598,770

North Dike	Length	Width	Area (sf)	No. of Drains	Linear Ft	Cost $
	8,025	400	3,210,000	44,533	5,789,290	$5,499,826
				Engineering		274,991
				Contingencies		27,499
				Total		5,802,316

Table 4. Estimated costs to install strip drains in dikes at Craney Island

The results of the strip drain test section analysis show that the amount of settlement in the foundation clay layer is less and slower than expected from Stark's 1993 report. Stark had used a weighted average of soil parameters to determine the settlement in the foundation clay under the test pad. Some of those values were obtained from Ishibashi's 1993 Phase I report. To update the expected settlement we took Stark's most recent (1996) void ratio and Cc values and used these with Ishibashi's dike geometry to determine the settlement expected in the marine clay layer under the existing dikes. We then used the slope geometry presented in Figures 7 and 13 to determine the expected settlement for the maximum elevation conditions. Table 5 presents the calculated settlements after the strip drains allow 100% consolidation.

Dike Condition	Initial void ratio	Settlement (ft)	Initial void ratio	Settlement (ft)
Exist Setback (Elev. +18)	2.2	8.0	2.5	7.4
Exist Dike (Elev. +30)	2.2	9.3.	2.5	8.6
Max Dike (Elev. +65)	2.2	12.6	2.5	11.5

Table 5. Calculated Settlements under Craney Island Dikes after 100% Consolidation

Time -Rate of Settlement Under Dikes.

To determine the amount of material that would be needed to maintain dike geometry during settlement we analyzed the settlement curves from the two strip drain test areas. Figure 1 shows the locations of the two test areas. The Phase I area was installed with strip drains placed at 6 foot centers. The Phase II site had the drains installed on 12 foot centers. The plot showing the settlement curves as well as the estimated continued settlement can be seen in Figure 17. The actual settlements were continued until the curves reached the total settlements estimated by Stark in his 1996 report. Using the curve for Phase II, since this has the drains at 12 feet on center, we calculated the time-rate of settlement. We developed Table 6 from this curve.

This settlement is based on the existing dike elevation, as we raise the dikes we can expect additional settlement in the range of three feet from the added surcharge. This settlement would be gradual as the dikes are raised, and should be able to be handled as part of the normal operations and maintenance.

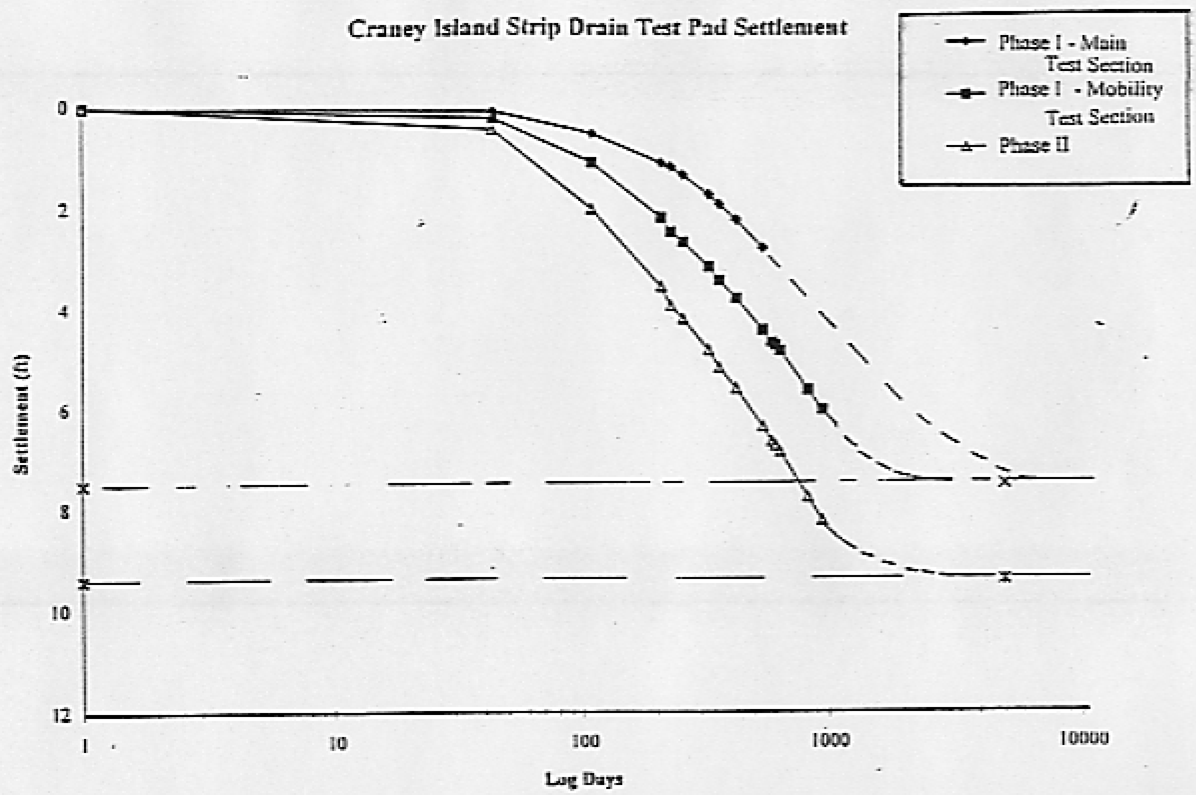

Figure 17. Settlement Curves for Phase I and Phase II Strip Drain Test Pad Areas

Time		1st yr	2nd yr	3rd yr	4th yr	5th yr	6th yr
Settlement (ft)		2.0	3.5	4.5	5.3	5.8	6
Settlement per yr		2	1.5	1.0	0.8	0.5	0.2

West Dike	Area (sf)	Dike Material (thousands of CY)					
South Cell	220,000	16	12	8	7	4	2
Center Cell	1,110,000	82	62	41	33	21	8
North Cell	1,110,000	82	62	41	33	21	8
	Total:	181	136	90	72	45	18

East Dike	Area (sf)	Dike Material (thousands of CY)					
South Cell	135,000	10	8	5	4	3	1
Center Cell	1,020,000	76	57	38	30	19	8
North Cell	1,190,000	88	66	44	35	22	9
	Total:	174	130	87	69	43	17

North Dike	Area (sf)	Dike Material (thousands of CY)					
	3,210,000	238	178	119	95	59	24

Table 6. Estimated amount of material needed to maintain dike elevations per year after strip drain installation.

Cost of Replacing Dike Material

To determine the amount of dike material needed to be replaced due to settlement we went back to the areas calculated for drain placement and Table 5 presenting the expected time-rate of settlement. The estimated amount of dike material needed over time is presented in Table 6 according to dike sections.

Bill Rawls, Supervisor at Craney Island, said that they presently have the labor and equipment to haul and place 100,000 cubic yards per year. They also have a contract for hauling which averaged 100,000 cubic yards this past year at a cost of $175,000. We conservatively estimate that it will cost about $200,000 for each 100,000 cubic yards of material needed. There are large pockets of suitable material for dike construction along the eastern side of island. Additionally, the latest dredging contract deposited a large amount of material in the northeast corner of the island. We can, at present assume that between existing material and new dredging jobs we will have enough material on the island to maintain the dikes. The strip drains should be placed in phases to prevent the need for additional material from exceeding the abilities to locate and haul it.

Cost of Replacing Weirs:

The weirs are expected to settle with the settlement of the dikes. The drains will need to be installed evenly around the boxes to facilitate even settlement of the boxes. Drains should also be placed on either side of the culvert pipes connected to the spillboxes, allowing the dikes to settle, while minimizing differential settlement between the wiers and the connecting culvert pipes. Operations has installed a telescoping weir with a flexible pipe in the center cell that will handle the additional drain requirements if one of the spillboxes were to become inoperable due to the dike settling.

Navy fuel pipe on the east side of Craney Island:

The Navy fuel line running along the east dike is active. There are two fuel lines, one 10-inch and one-eight inch, at a depth of about eight feet, that would need to be moved if we caused settlement of the pipe foundation. Settlement calculations for the east dike show that we could expect settlement of four to six feet after drains installation and 100% consolidation. The stability analysis indicates that we can raise the dike elevations without placing the drains close enough to the pipeline to cause settlement of the foundation. Therefore, the Navy pipeline should not be adversly affected by the drain installation.

Instrumentation:

We recommend placing two monitoring clusters consisting of 3 piezometers, an inclinometer, a settlement plate and 3 borros downhole settlement anchors, in each compartment of the dikes, or a minimum of 5 clusters per dike. Each of the dikes has an existing instrumentation cluster that was installed in 1989, but does not have any borros anchors. The piezometers will enable us to monitor the dissipation in pore pressure during consolidation. The borros anchors will provide settlement data from different elevations under the dikes. An estimate of the cost to install each instrument cluster is $20,000.

These cluster should be read approximately four times a year during the first three years after drain installation and then twice a year there after. The values from the piezometers and the borros settlement anchors should be compared to determine if the marine clay is approaching 100% consolidation. An estimate for the annual cost to monitor the instrumentation is $40,000 annually.

Strip Drain Cost Summary

Table 7 shows the summary of the costs ($M) involved in installing strip drains in all of the dikes at Craney Island.

	Drain Installation	Maintain Dikes	Instrumentation Installation	Instrumentation Monitoring*
West Dike	$4.79	$1.08	$0.1	
East Dike	$4.59	$1.04	$0.1	
North Dike	$5.80	$1.40	$0.1	
Subtotal	$15.18	$3.52	$0.3	$.2
Total				$19.20 M

* assuming a five year period

Table 7. Summary of costs (FY97 dollars) of Installing Strip Drains in the Dikes at Craney Island in Millions of Dollars

LIGHTWEIGHT FILL COSTS

The operations staff at Craney Island estimates that the rip rap and concrete debris area along the north dike is some 2000 feet long. Using the amount of lightweight fill of 2800 sf required in the stability analysis, we calculate a volume of 207,500 CY needed in the area. Lightweight aggregate, such as Solite, can be barged in, but will cost about $42/ton, which computes to a total of $7.5 M for this size area.

Another option for lightweight material is shredded tires. The tires are typically free and a shredding plant cost around $500,000 in 1993. This option would need to be investigated further as the use of geotextiles materials to contain the tires and prevent the fines in the dredge material from filling the voids would need to be analyzed.

RECOMMENDATIONS:

Preliminary estimates show that installing strip drains in the dikes is less expensive than installing them in the dredge material and will also provide greater storage area. Stark's 1991 report estimates that the cost of placing drains in the dredge material area would be $25.8 M in FY 91 dollars and provide an additional 10 vertical feet of storage area. Placing drains in the dikes could increase our vertical storage by an average of 20 vertical feet and cost the Norfolk District approximately $19.2 M.

Recommend that a staged construction effort be planned to place strip drains in the dikes at Craney Island. This plan would need to address the amount of material available for maintaining the dike heights during settlement as well as the availability of a contract to haul and place the material. The west dike should be constructed in three stages to allow settlement of each compartment and ensure that no more than one containment area spill box is inoperable at a time.

We also need to address the extent of the rip rap placed on the dikes in the northeast corner of the island. After the extent of the rip rap is determined we can determine the cost to remove the rip rap prior to drain installation, or the possibility of using preaugered holes to place the drains in these area. This would raise the cost of drain placement, but would most likely be less expensive than using a lightweight aggregate fill.

We need to establish a monitoring program that incorporates the use of installed instrumentation as well as in-situ testing. A series of instrumentation clusters consisting of inclinometers, peizometers, and settlement reading devices should be installed along the top and toe of the dikes. Every effort should be made to ensure that the instrumentation (settlement plates and piezometers) already in place in the Phase I Test Pad and Phase II areas are maintained and the data collected and anlayzed at least semiannually. Additional testing for the increase in shear stregth and settlement parameters should also be performed prior to drain installation to establish a baseline and then yearly to determine if the values calculated herein are valid.

GeoEnvironmental Branch can monitor and analyze the data for an estimated $40,000 per year. Additionally, we can obtain a contractor to perform Cone Penetrometer Testing (CPT) and Dilatometer Testing (DMT), which would provide us with the ability to determine the settlement and percent consolidation values of the settling clay layer. The cost of this testing typically runs about $9/lf with an additional mobilization charge. An annual estimate for this testing and analysis is $50,000 depending on the amount of testing required.

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